

Chapter 10 Engineering Vibration Investigations

10-1. Earthquake-Resistant Design

Many Corps' projects could potentially be impacted by earthquakes. HQUSACE is conducting Corps-directed research for particular concerns with dam and reservoir projects. This effort, the Civil Works - Earthquake Engineering Research Program, should provide valuable tools to design resistant structures under earthquake loading. Vast resources of research, publications, and designs for earthquake studies are available in government and public domains.

a. Guidance. Several present engineering manuals and engineering regulations provide guidance for considering earthquake impacts on Corps' projects. Several documents are under current revision or review. As the Earthquake Engineering Research Program and other study advances become available, HQUSACE will update its provisions for design and rehabilitation.

b. Earthquake and project studies. The provided guidance can only be applied with knowledge of the regional seismicity, regional geologic regime, geologic structure and faulting in the vicinity of the project, the geology of the site, and the site foundation's engineering properties.

(1) Interdisciplinary team. Districts undertaking studies to provide the geophysical, geological, and geotechnical data for a project should consider interdisciplinary teams. A study manager would normally lead the assembled group with some or all the following types of experience:

- (a) Engineering seismology.
- (b) Strong-motion geophysics.
- (c) Structural geology.
- (d) Engineering geology.
- (e) Foundation/geotechnical engineering.
- (f) Hydraulics engineering.
- (g) Structural engineering.

The diverse interests and differing technical language of these team members require close coordination to maintain the project's objective. Team members may not all be within the District's staff or even government service. A cohesive body can establish specific products in harmony with the use of the product in achieving the project goal. The individual study components will more likely suit the following user of the product, if the interdisciplinary team acts as a body requesting information with explicitly stated goals.

(2) Geophysical investigations. Many of this manual's procedures will provide important data to the solution of particular objectives. Some possible resolutions might be as follows:

- (a) Location of faults.
- (b) Crosshole shear velocities of the foundation and embankment on built structures.
- (c) Downhole logging of borings for soil or rock properties or unit contacts.

10-2. Vibration Concerns

Blasting programs and vibrating machine foundations compose a set of problems that will not employ procedures from this manual. The sole exception might be S-wave refraction or surface wave studies to determine the damping of founding soil material for a machine foundation.

a. Blasting programs. Rock removal and rock quarrying or blast demolition at projects produce three general hazards: ground vibrations, airblast, and projectiles. Thrown ejecta from explosions are solely resolved by the blasting contractor and the risk only occurs near the blasting area. Airblast or noise causes public objections and may break windows. Airblast abatement will be enhanced by proper stemming (granular fill of the blast hole) and avoiding shots during adverse weather or day-time hours. Ground vibrations (and damage to structures) increase with increased explosive weight, reduction of distance to important locations, and adverse geologic factors.

- (1) Reduction of blast vibration.

(a) The charge weight per delay is the most important factor within the contractor's control to limit ground motion. Better specifications require that the scaled

distance be limited for the initial shots of the program. Scaled distance is the straight line distance from the shot point of a blast to the closest structure or measurement point divided by the square root of the charge weight per significant delay. Delays are significant when they exceed the longer of 9 ms or 10 percent of the total delay period. Scaled distances above 50 ft/square root of pounds will normally cause no damage to a structure with a substantial safety factor. As the contract progresses, the contractor should be allowed to lower the production scaled distance as long as no damage has occurred.

(b) The distance from the area of shooting and the site geology are not within the contractor's control. The contractor, upon recognizing a difficult condition can carefully select how to progress with the work, at minimum, to approach from a favorable direction. Other controlled blasting measures, such as line drilling and cushion or presplit blasting, may need to be considered with adverse geometry or geology.

(2) Efficient blasting programs. Corps' projects may either direct or be affected by other blasting uses. The use of blast-motion seismographs is recommended when there are concerns on government property from the blasting of others. Directed blasting contracts by the Corps may have unforeseen outcomes, if the programs are not carefully considered. The art of blasting has developed significantly in recent decades. Buildings, chimneys, and bridges have been safely removed without damaging adjacent structures.

(a) Government-directed blasting contracts will normally be more expensive and not as likely to achieve quality results. Performance contracts for blasting with specific contract safety limitations secure better production at lower costs. The contractor would have a specified goal in a performance contract. The contractor may use any cost-effective method to secure the goal within the limitation of the contract. Contract limitations would be as follows:

- Worker safety.
- Avoiding structural damage.
- Maximum ground vibrations at provided locations.
- Limiting airblast and flyrock.

(b) Performance contracts have another important benefit besides quality results. Performance contracts reduce the government's liability while blasting is being

accomplished. The contractor is choosing the method to perform the goal without government approval. The specification should provide that required information be submitted to the government before each shot without the approval of the shooting program.

b. Machine vibrations. Design of large vibrating machines is normally undertaken by structural engineers. Vibrating machinery that develops harmful oscillations will normally have expensive remediation. Structural engineers may request geotechnical foundation designs to rehabilitate or install large machinery. Base isolation, adjusting the block foundation's frequency, or assessing the foundation's damping may need surface wave techniques to provide effective solutions.

10-3. Acoustic Emissions

a. Monitoring. The monitoring of acoustic emissions or microseismic activity has been used to isolate distressed portions of engineering structures as load is increased. In earth materials, it has been used to predict failure of landslides and other unstable natural structures. Progressive or alternate loading can result in local structural failures at points where the stress concentration exceeds the strength of the material. Due to the inherent inhomogeneity of most materials, each failure in turn alters the natural strength of the adjacent material. As the stresses (and resultant strains) are redistributed in the structure, stress (seismic) waves are emitted contributing to the phenomenon of spontaneous stress-wave emissions, known as *acoustic emissions*.

(1) Individual acoustic emissions are frequent, spontaneous, and normal in most structures coming under load. The monitoring of the signals is thus complicated by the requirement of recognizing what is a "normal" response to loading, and what is a signal of incipient failure. As individual events are not ordinarily important in and of themselves, the instrumentation is usually set up to count only events stronger than a certain background and to normalize the count of these events over time. Thus, number of events per minute is the typical monitoring parameter. The amount and type of monitoring is adjusted to the expected load profile and to the expected failure time horizon. Thus, sheet piles under river loads may be monitored only for an hour once a day to get a representative number and then monitored continuously under flood conditions to measure pile performance and/or long-term variation in response to similar loads. Landslides may be similarly monitored on a weekly basis during the dry season, and at some daily rate when water is present and failure more likely.

(2) Equipment must also be fitted to the scale of the problem. As recording fidelity is not important, often the transducer is mounted so as to achieve some mechanical amplification of the signal. Steel rods driven to bedrock with accelerometers mounted within a meter above the surface have been used in landslide investigations, while pipes welded to piles have been used to mount velocity transducers in other studies. Specialized instrumentation is available which will report the number of events per minute, the average number of counts per minute, and the number of counts per event. Obviously there is substantial latitude in defining what is an event and what is a count. Additionally, mechanical amplification will accentuate the effect of any external noise impacting the structure.

b. Acoustic emission recordings.

(1) Failure-prone underground mines have used similar monitoring systems with one important difference. By using an array of detectors and a real-time processor, locations of events within an active mine have been obtained on a daily basis. When presented as a map, this information can be of economic benefit to mine operators.

(2) One problem with acoustic emission analysis is the determination of success. The intent of the analysis should be to define in advance an adverse occurrence by its distinctive emission rate. If the pattern of acoustic emissions leading to failure is recognized only after the failure, the program has not been a success. Any program should undergo a thorough evaluation before it starts and satisfactory answers to the following questions should be accepted by all participants, including the consumer of the information.

(a) What phenomena are being directly monitored?

(b) What properties are being inferred from the measurement (attempted to be resolved)?

(c) What horizon of prediction is being investigated, and are the events sufficiently detailed or numerous that success or failure can be measured?

(d) What constitutes success or failure?

(e) Considerable empirical adaptation of these methods to each site-specific area is required.

10-4. Nondestructive Testing

a. System types. Nondestructive testing is available through a variety of sources. Systems may be based upon electromagnetic, seismic, thermal, and x-ray evaluations. Tests do not “harm” the evaluated feature and are considered diagnostic of each element tested. Better systems offer real-time evaluation of the feature.

b. Seismic deployment. Most seismic versions of nondestructive testing methods as applied on construction sites rely on the measurement of the impulse response of a column, beam, or similar structure. A calibrated hammer is used to strike the structure and the resulting response is measured by a well-calibrated accelerometer or other transducer. A spectrum analyzer is used to remove the variations in the input signal and the impulse response is displayed in either spectral or time-domain form. If sufficient ingenuity is used to place the source and receiver, the results can be very diagnostic.

c. Procedure. A testing method is most useful when distinguishing between “good” units and “bad” structures. The method is calibrated on the known good structures and then the rest can be tested for major differences from the good ones. Obviously, the amount of change necessary to condemn a column and the range of acceptability should be decided by an experienced specialist in this field. As all structures are different and have significantly different responses, considerable engineering judgement is necessary to successfully apply nondestructive testing.